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13. ABSTRACT (Maximum 200 words)

During the past year of the granting period, we have continued to make substantial progress consistent with the objectives outlined in our latest proposal. 1) We have completed an extensive analysis of and succeeded in publishing a very comprehensive set of data concerning the amount of "comodulation masking release" (CMR) that can be obtained when the coherent envelope information is presented successively rather than simultaneously. It was determined that "off-frequency" information, such as that which usually produces a CMR, can provide only a very small release from masking when it is presented prior and subsequent to the temporal interval containing the signal. The most striking finding was that the threshold for detecting a 1-kHz tone masked by an 50-Hz-wide band of noise centered on 1 kHz, was reduced by 7 dB when an identical, "on-frequency", masking noise was presented in all four intervals of our two-cue, two-interval, forced-choice procedure. 2) We finished three other papers, one of which was published and two of which have been revised and resubmitted. 3) We are currently collecting data concerning how varying the forward fringe of a masker affects the magnitude of the binaural masking-level difference. The experiments are being conducted with low-frequency signals where the interaural cues are conveyed by the fine-structure of the waveform and with high-frequency signals where the interaural cues are conveyed via the envelope of the waveform.

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RE: AFOSR-89-0030

Monaural and Binaural Processing of Complex Waveforms

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ABSTRACT OF TECHNICAL PROGRESS (November 1, 1992 - October 31, 1993)

During the past year of the granting period, we have continued to make substantial progress consistent with the objectives outlined in our latest proposal.

1) We have completed an extensive analysis of and succeeded in publishing a very comprehensive set of data concerning the amount of "comodulation masking release" (CMR) that can be obtained when the coherent envelope information is presented successively rather than simultaneously. It was determined that "off-frequency" information, such as that which usually produces a CMR, can provide only a very small release from masking when it is presented prior and subsequent to the temporal interval containing the signal. The most striking finding was that the threshold for detecting a 1-kHz tone masked by an 50-Hz-wide band of noise centered on 1 kHz, was reduced by 7 dB when an identical, "on-frequency", masking noise was presented in all four intervals of our two-cue, two-interval, forced-choice procedure.

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A) Statement of Work

The purpose of the proposed research continues to be a broader understanding of the manners by which the "monaural" and "binaural" auditory systems process information in complex sounds. Our empirical investigations are intimately related to our theoretical orientation, on the one hand, and to our strain to incorporate and to understand diverse, yet certainly related behavioral phenomena on the other.

One subset of experiments concerns our recent finding that the detectability of an 800-Hz tone (the target) in the N_0S_π configuration is degraded or "interfered with" by the presence of a 400-Hz tone gated with the same temporal characteristics as the target in both intervals of a two-interval, forced-choice task. We completed a series of experiments in which various temporal and spectral aspects of the target, interferer and accompanying masking noise are varied in order to better characterize the mechanism or mechanisms responsible for interference. We were able to determine that the interference we observed is independent of mechanisms that underlie the processing of complex stimuli which, in turn, mediate the segregation of sources of sound.

A second subset of experiments concerns the effect of temporal/spectral variations on the masking level difference, but in a different context. Here, we are investigating how the detectability of tonal targets is enhanced by turning on the relevant masking energy earlier and earlier. We have been and will continue to collect such data for high-frequency targets and narrow-band maskers.

A third subset of experiments represents a continuation of our efforts to elucidate the temporal properties of stimuli required to produce a sizeable comodulation masking-release (CMR). Beyond discovering that the CMR does not occur or is greatly diminished for short, pulsed stimuli, our efforts have focused on measuring the amount of comodulation masking release that can be obtained when the envelope-based information presented successively rather than simultaneously.

A fourth, rather large, subset of experiments concerns the detectability of interaural disparities that occur shortly after the beginning of an acoustic event. These experiments are designed to investigate phenomena typically discussed in the context of the "precedence" effect. We are especially interested in determining how the detectability of such interaural information is affected by other binaural information in close (or remote) spectral/temporal proximity. Several of the experiments are designed to assess sensitivity to interaural disparities when the listener is uncertain about the temporal/spectral placement of the cues to be detected.

Finally, we have continued our fruitful collaboration with Dr. Richard Stern to extend a complex, comprehensive, pattern-processing model of binaural hearing that utilizes the cross-correlation functions of temporally and spectrally complex stimuli to describe behavior phenomena.

B) Specific Progress

During the past year, which represents the second year of the new granting period, we have made substantial progress consistent with the objectives outlined in our latest proposal. As is our norm, we will discuss our progress in three separate, but related areas. They are 1) collection of behavioral data; 2) publication of empirical data and 3) extension of our comprehensive, complex model of binaural processing. In the interest of brevity, we will only mention, and not document extensively, development of new software necessary to conduct the behavioral experiments and 2) development of computer simulations to assist in the analysis and interpretation of our behavioral data as well as those from the laboratory of

Gerald Kidd and his collaborator, Christine Mason. Such software development was absolutely crucial to the full understanding of the data and their publication in the Journal of the Acoustical Society of America.

We have had one paper published, two accepted for publication and a fourth is currently under review after being revised. In addition, we have completed a chapter for a book concerning models of binaural interaction in collaboration with Dr. Richard Stern, our consultant. In addition, two other chapters are being prepared for the proceedings of the meeting in Dayton concerning binaural and spatial hearing that was sponsored by AFOSR. We have included one reprint and four manuscripts.

The Bernstein and Trahiotis (1993) paper appeared in the August issue of the Journal of the Acoustical Society of America. This paper reports the latest in a series of experiments concerning spectral interference in a binaural detection task. The data concerned the effects of temporal fringes and the bandwidth of the masker. The two major results are that much more interference is observed with narrow-band than with wide-band maskers and that an asynchronous forward fringe of the interferer of up to 320 ms does not restore performance to that obtained with continuous interferers, which are relatively ineffective. These data mesh well with those recently reported by Woods and Colburn (JASA,1992) and Stellmack and Dye (1993).

A second Bernstein and Trahiotis (1993) paper scheduled for publication in the February, 1994 issue of the Journal of the Acoustical Society of America, concerns our research which began to determine the amount of "comodulation masking release" (CMR) that could be obtained when the coherent envelope information was presented <u>successively</u> rather than simultaneously. The series of experiments evolved to include an assessment of the actual cues listeners are use when detecting a tone masked by a narrow band of noise.

By utilizing a very large number of control conditions and measuring detectability with stimuli randomly "roved" in level, we believe we were able to discover when and how envelope information is utilized by the listeners. The original experiment blossomed into an investigation concerning advantages to the listener provided by reproducible noise, conditions under which listeners base their decisions on "energy" and how changes in the statistics of the signal-plus-noise envelope affect performance. The most important finding of these experiments is that: 1) "off-frequency" information, such as that which provides a CMR, provides little, if any, advantage for detection and 2) "on-frequency" information can reduce thresholds by 5 dB or so.

Specifically, listeners' detection thresholds were measured for a 125-ms, 1 kHz tonal signal masked by a similarly-gated 50-Hz-wide band of noise. A two-interval, adaptive, forced-choice procedure either with or without temporally-surrounding cuing intervals containing 50-Hz-wide bands of noise was employed. When the cues were present, their center frequency was either 1 kHz (on-frequency) or 900 Hz or 700 Hz (off-frequency). In the conditions of principal interest, the envelopes and phase-modulations of the bands of noise were "frozen" across the four intervals that defined a trial, but were chosen randomly across trials. Thresholds were lowest with cues centered at 1 kHz and increased substantially when the center frequency of the cues was changed to 900 Hz or 700 Hz. With cues centered at 700 Hz, performance was equivalent to that obtained without cues and with the masking noise "frozen" across the two intervals that defined a trial. A similar pattern of results was obtained with high-frequency stimuli, where sensitivity to fine-structure information is greatly reduced. Roving the level of the stimuli over a 40-dB range generally reduced sensitivity but did not greatly affect the overall pattern of the data. Thresholds obtained in the two-interval task with masking waveforms chosen randomly were compared with thresholds obtained when the masking waveform was "frozen" within, but not across, trials.

Differences in threshold appeared to be accounted for by the listeners' use of changes in the mean-slope of the envelope of the noise produced by adding the tonal signal. We spent a great deal of time and effort pursuing the analysis this complex series of experiments and were successful in extending our analyses to account for data recently published in a paper by Kidd et al. Interestingly, our analysis showed that the envelope mean-slope statistic was quite successful in accounting for their data, a conclusion counter to the one in their paper. Their analysis considered only the properties of the masking waveforms, while ours considered the differences in the statistic calculated for each signal-plus-masker and masker combination.

Another paper, currently revised and expected to be accepted according to the editor's letter, (Buell, Trahiotis and Bernstein, 1993) concerns the lateralization of bands of noise as a function of combinations of interaural intensitive differences, interaural temporal differences, and bandwidth. Listeners indicated the intracranial position of bands of noise (from 50 Hz to 400 Hz in width) for several combinations of interaural intensitive differences (IID), and interaural temporal differences (ITD), and/or interaural phase differences (IPD).

All ITD and IPD combinations produced an interaural delay of 1500 μs at the center frequency of the noise. The interaural phase spectra were constructed to produce several patterns of putative cross-correlation functions. Potency of IIDs depended greatly on particular combinations of bandwidth, ITD and IPD. For some combinations, changing the IID by only 3 dB resulted in large shifts in laterality (sometimes moving the image from near one ear to near the other). The complex interactions observed make the results incompatible with the traditional notion that IIDs simply act as weights or scalars. Rather, IIDs act in two distinct manners: 1) as independent scalar quantities that we believe are applied subsequent to the output of the cross correlator and 2) by interacting with specific combinations of bandwidth and ITD/IPD, which we believe reflects an action within the cross correlation surface.

A fourth paper (Bernstein and Trahiotis) concerns the detection of interaural delay in high-frequency SAM tones, two-tone complexes, and bands of noise. We found that sensitivity to ongoing, envelope-based, ITD at a center frequency of 4 kHz or 8 kHz depended upon the type of stimulus conveying the delay. For two-tone complexes and SAM tones, which have discrete spectra and deterministic temporal envelopes, sensitivity to ITD appeared to diminish as the rate of fluctuation of the envelope increased. This decrease in sensitivity did not appear to be due to critical-band-like filtering that could result in reduced depth of modulation. Rather, the data appeared to be explicable in terms of Nuetzel and Hafter's (1981) notion that listeners are unable to "follow" or encode high rates of fluctuation of the envelope.

Sensitivity to ITD conveyed by bands of noise, which are spectrally continuous and have stochastic envelope functions, remained relatively unaffected as a function of bandwidth. We believe that listeners may have maintained their thresholds by shifting the center of their internal "filters" or "critical bands" below the center frequency of the stimulus. This strategy would reduce the effective rate of fluctuation of the envelope with no loss in depth of modulation. Generally, sensitivity to ITD decreased as center frequency was increased from 4 kHz to 8 kHz but the relations among the data were essentially unchanged. Increasing the center frequency to 12 kHz resulted in unexpectedly, extremely poor performance. The bulk of these experiments were conducted with two separate sets of earphones. Sennheiser-250 earphones were used because the response of the TDH-39s at 12 kHz was insufficient. Data at center frequencies of 4 kHz and 8 kHz were collected with both the Sennheiser and TDH earphones to ensure that the results we obtained were not idiosyncratic to the Sennheisers. These experiments were not proposed to AFOSR. They were conducted primarily with other support. However, a significant portion of the research was supported by AFOSR funds.

A chapter entitled, "Models of Binaural Interaction" was prepared by Dr. Richard M. Stern and Dr. Constantine Trahiotis for volume 6 of the Handbook of Perception and Cognition, Hearing edited by B.C.J. Moore. The goal of the chapter was to provide an intuitive understanding of how cross-correlation-based binaural models work, and an appreciation of their capabilities and limitations in describing a variety of binaural phenomena. We are also preparing two chapters for the proceedings of the conferenceon binaural and spatial hearing that was held earlier this year in Dayton, Ohio.

We are currently collecting data concerning how varying the forward fringe of a masker affects the magnitude of the binaural masking-level difference. The experiments are being conducted with low-frequency signals where the interaural cues are conveyed by the fine-structure of the waveform and with high-frequency signals where the interaural cues are conveyed via the envelope of the waveform. The main parameters of interest are 1) duration (of the signal and, separately, of the masker) and 2) the bandwidth of the masker. The experiments are conducted using a single-interval procedure and both homophasic and antiphasic conditions are being run. Beyond providing data concerning similarities and differences in binaural processing at high and low frequencies, the data will shed light on the influence of spectral region on binaural "sluggishness", a term referring to the binaural system's limited ability to process dynamically changing interaural cues.

C) Publications

Bernstein, L. R. and Trahiotis, C. (1993). "Spectral interference in a binaural detection task: Effects of temporal fringe and masking bandwidth," J. Acoust. Soc. Am., 94, 735-742

Bernstein, L. R. and Trahiotis, C. (1993). "The effects of non-simultaneous on-frequency and off-frequency cues on the detection of a tonal signal masked by narrow-band noise," J. Acoust. Soc. Am., in press.

Buell, T. N., Trahiotis, C., and Bernstein, L. R. (1993). "Lateralization of bands of noise as a function of combinations of interaural intensitive differences, interaural temporal differences, and bandwidth," J. Acoust. Soc. Am., revision with editor, acceptance expected forthwith.

Bernstein, L. R. and Trahiotis, C. (1993). "Detection of interaural delay in high-frequency SAM tones, two-tone complexes, and bands of noise," J. Acoust. Soc. Am., revision with editor, acceptance expected forthwith.

Stern, R.M., Jr. and Trahiotis, C. (1993). "Models of binaural interaction," to appear in Handbook of Perception and Cognition, Volume 6: Hearing, edited by B.C.J. Moore (Academic Press, New York).

D) Interactions

Two presentations were made at the conference concerning binaural and spatial hearing held in Dayton Ohio and sponsored by AFOSR:

Bernstein, L. R. (1993). "Lateralization and the detection/discrimination of interaural disparities: Modern earphone-based studies."

Buell, T.N. and Trahiotis, C. (1993). "Combination of interaural cues: How interaural disparities interact within and across spectral regions."